Event geometrical anisotropy and fluctuation viewed by HBT interferometry

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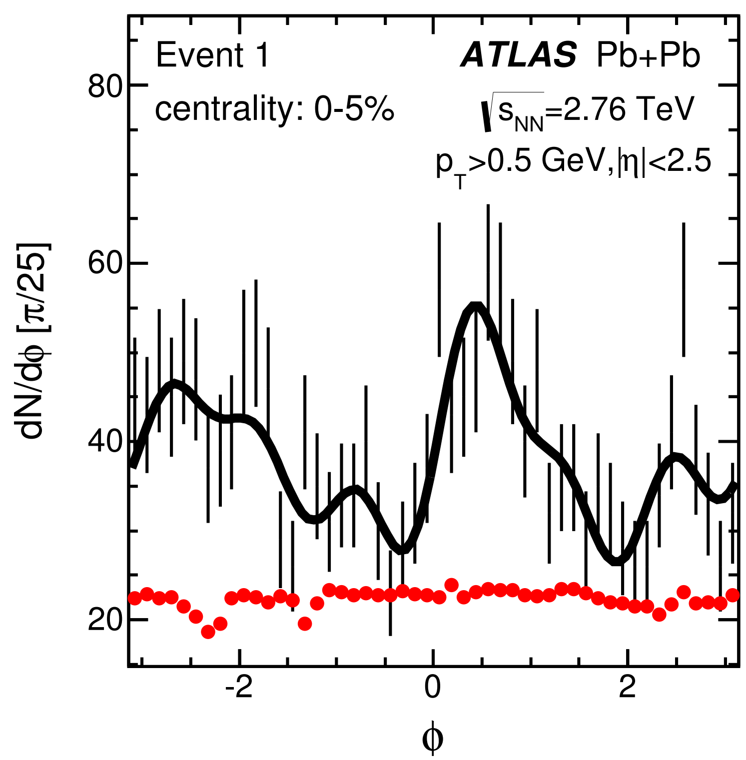
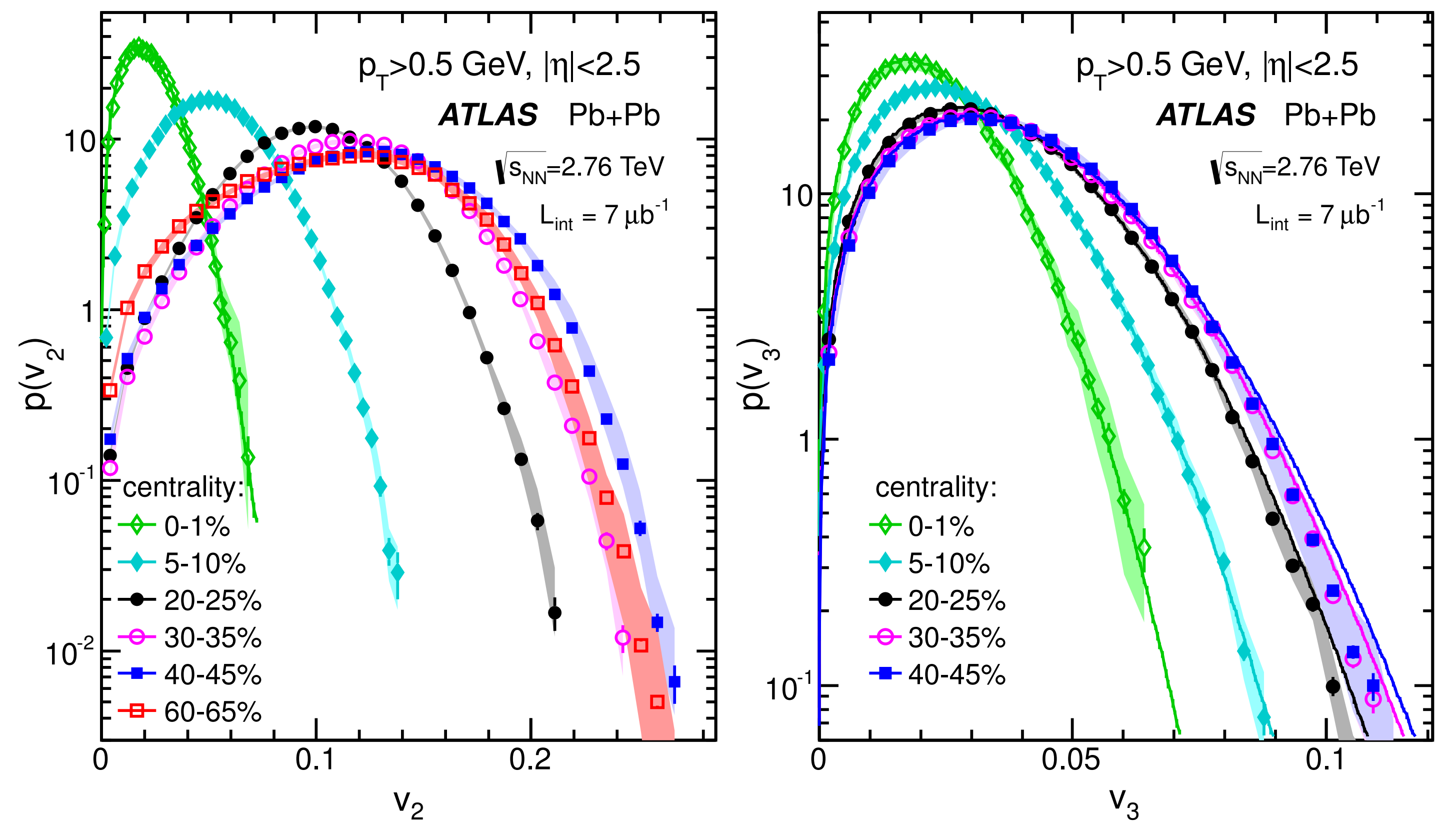
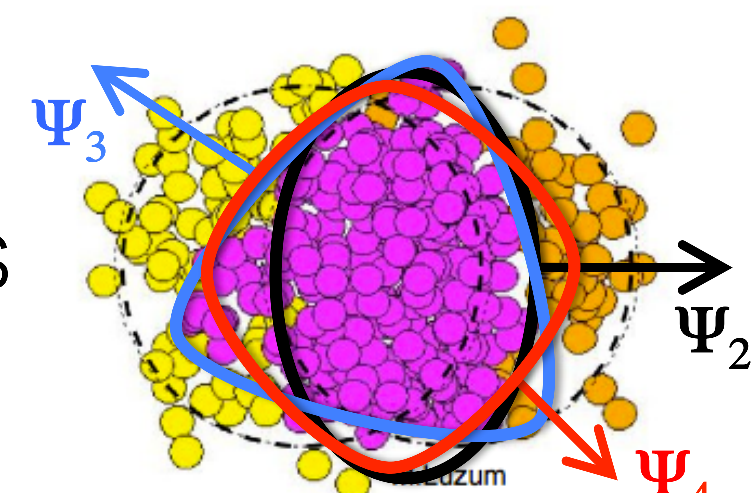
Event-by-event fluctuation of v_n

ATLAS, JHEP11(2013)183





$$\frac{dN}{d\phi} \propto 1 + \Sigma v_n \cos[n(\phi - \Psi_n)]$$

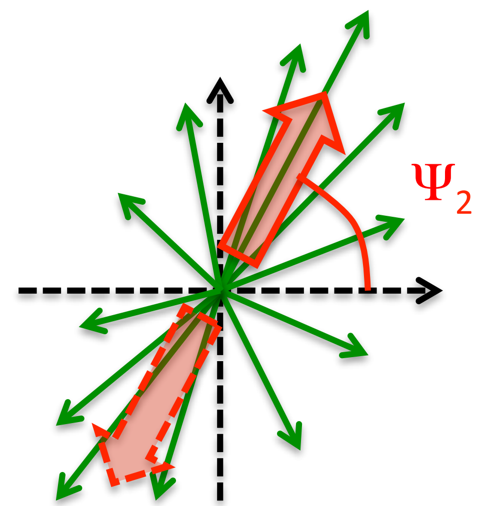


- Charged particles v_n in e-b-e analysis at ATLAS
- Large event-by-event fluctuation of v_n
  - Possible probe to the initial geometry

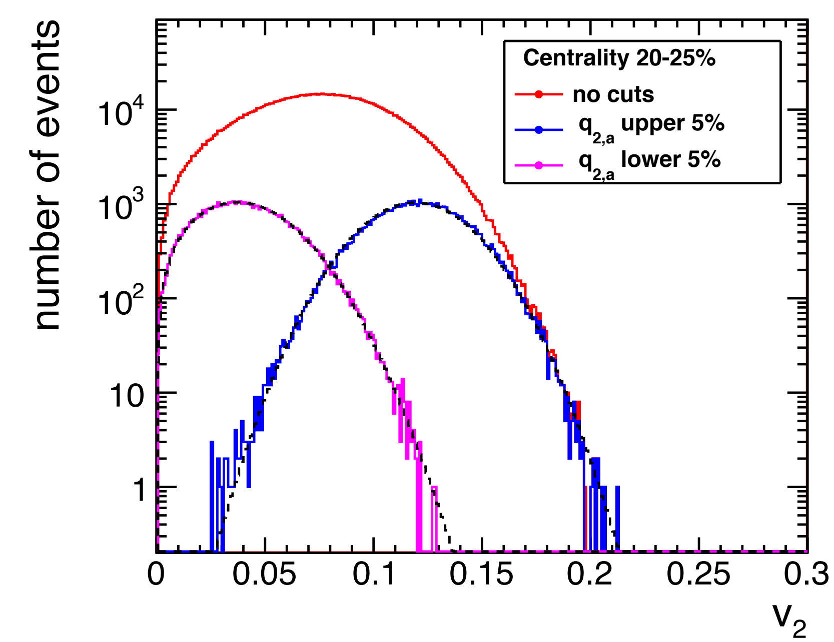
Event shape engineering

- Event shape engineering (ESE)
  - J. Schukraft et al., arXiv:1208.4563
  - Selecting v_n strength by the magnitude of flow vector

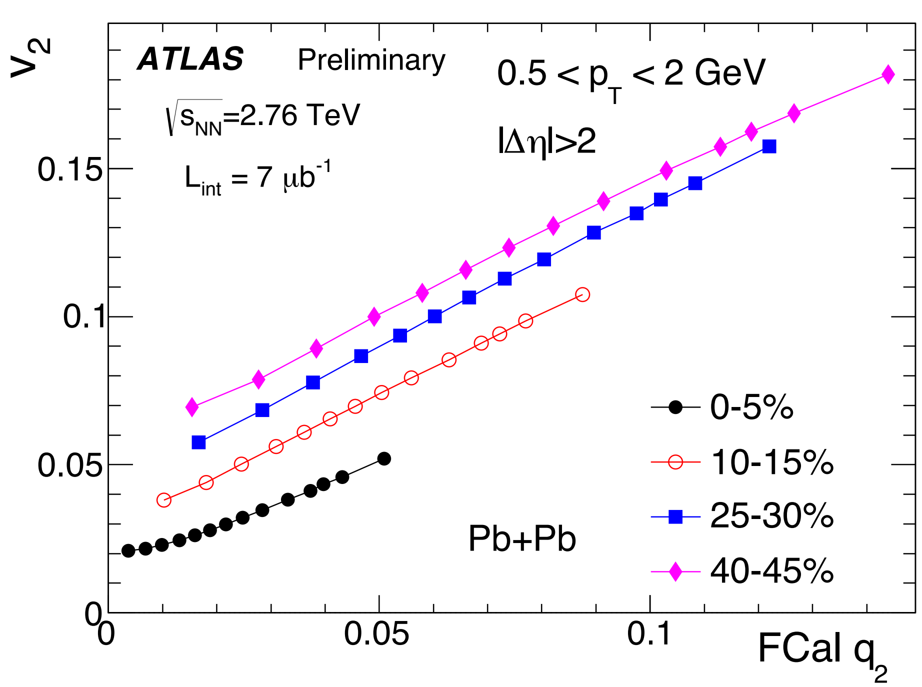
$$Q_{2,x} = \Sigma w_i \cos(2\phi)$$
$$Q_{2,y} = \Sigma w_i \sin(2\phi)$$
$$Q_2 = \sqrt{Q_{2,x}^2 + Q_{2,y}^2}/\sqrt{M}$$



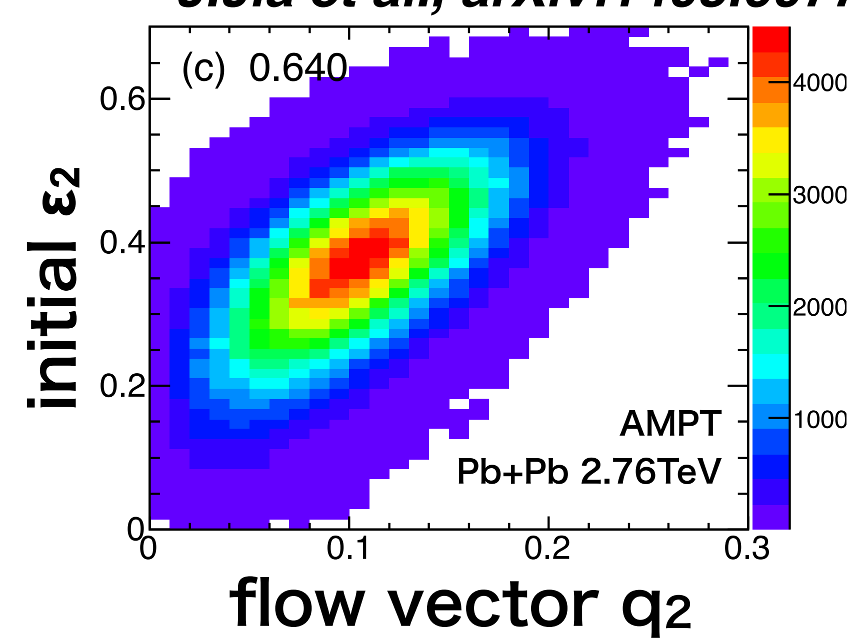
J.Schukraft et al., arXiv:1208.4563



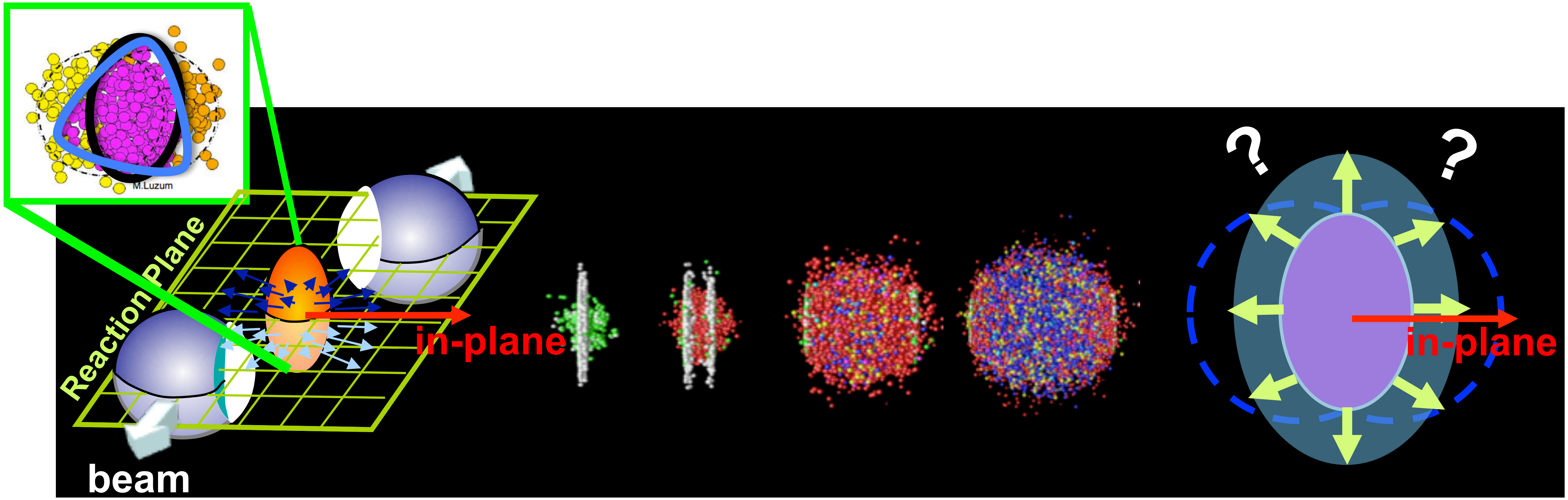
- **Possibly control the initial geometry**



J.Jia et al., arXiv:1403.6077

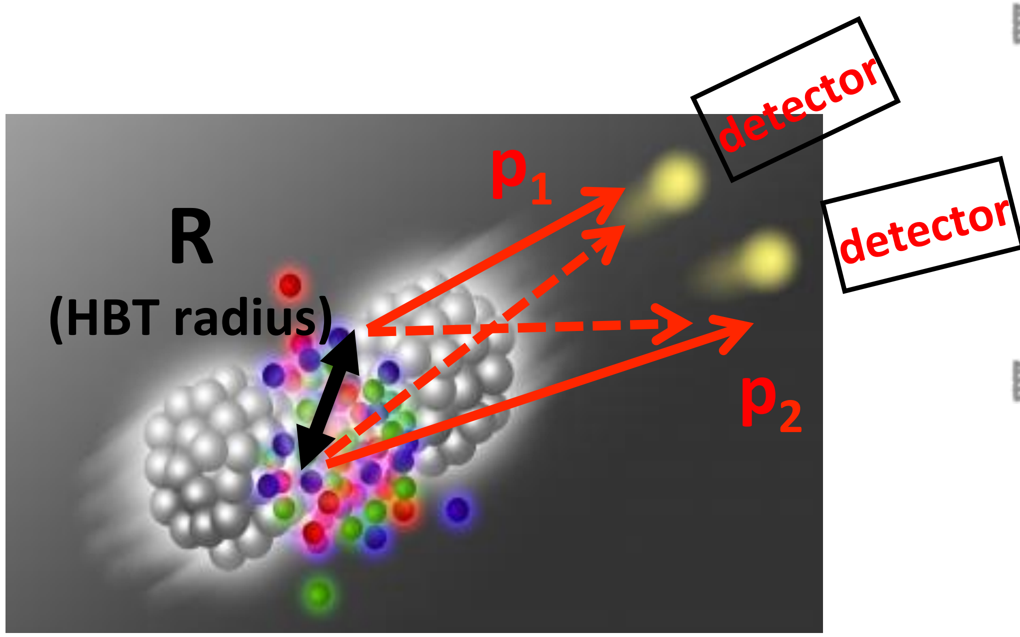


What is the final spatial dist.?



- Event shape selection provides us more accurate connection between initial and final source eccentricity?
  - Large $\varepsilon_{\text{init}}$ leads to large $\varepsilon_{\text{final}}$? or to less ellipticity due to large v_2?
- Final source eccentricity can be probed by HBT interferometry

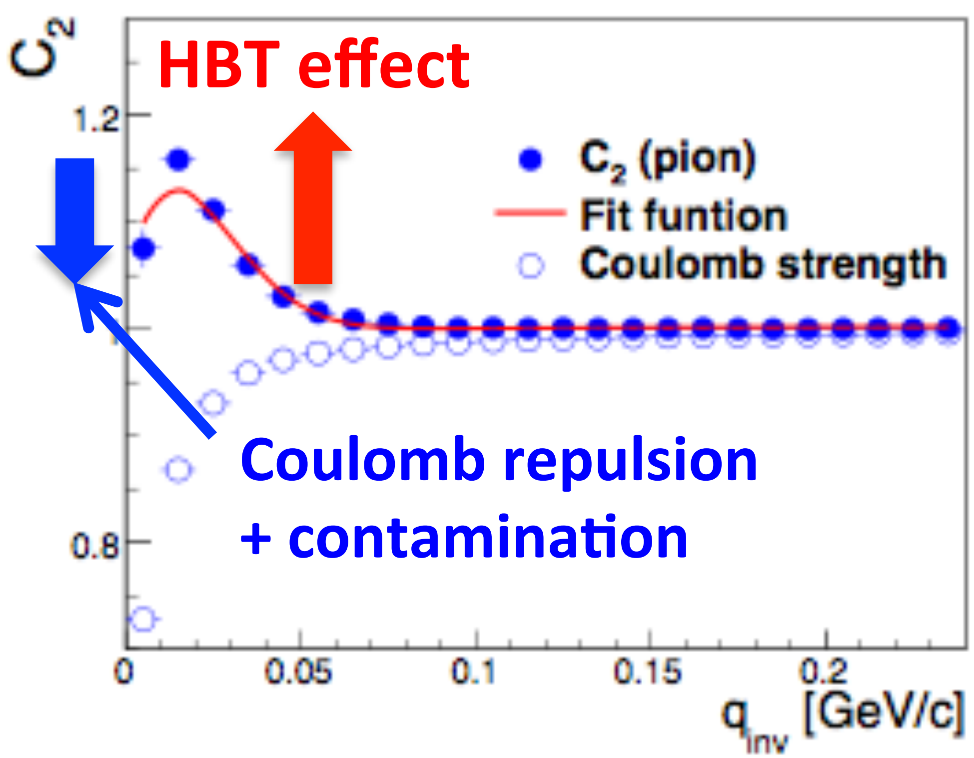
HBT interferometry



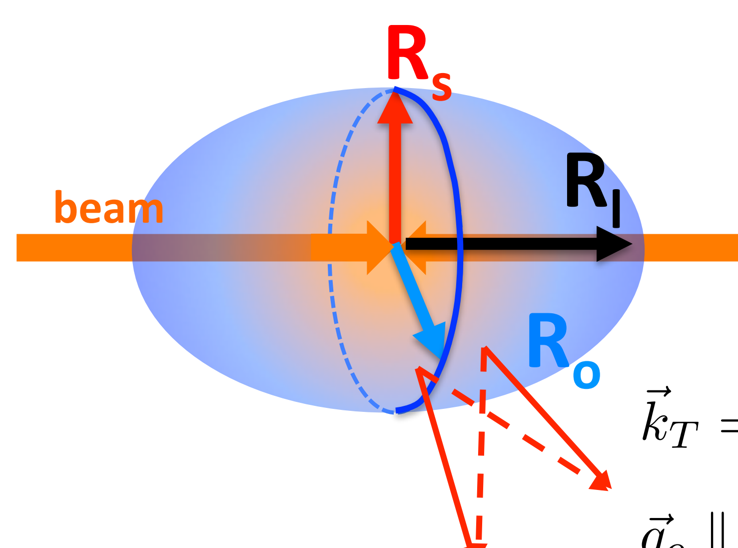
- Hanbury Brown and Twiss effect (1950s)
  - Quantum interference b/w two identical particles
  - Due to (a)symmetrization of the wave function of identical bosons(fermions)
- Correlation function

$$q = p_1 - p_2$$

$$C_2 = \frac{P(p_1, p_2)}{P(p_1)P(p_2)} \approx 1 + |\tilde{\rho}(q)|^2 = 1 + \exp(-R^2 q^2)$$



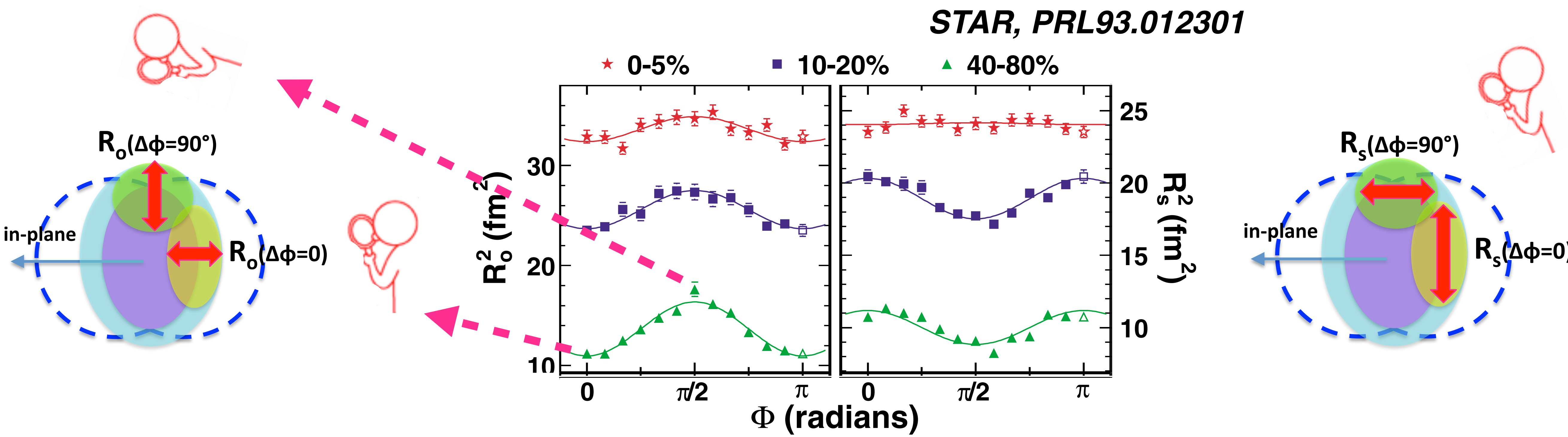
$$\begin{aligned} C_2 =& C_2^{core} + C_2^{halo} \\ =& [\lambda(1+G)F_{coul}] + [1-\lambda] \\ G =& \exp(-R_s^2 q_s^2 - R_o^2 q_o^2 - R_l^2 q_l^2 - 2R_{os}^2 q_s q_o) \end{aligned}$$



$$\vec{k}_T = \frac{1}{2}(\vec{p}_{T1} + \vec{p}_{T2})$$

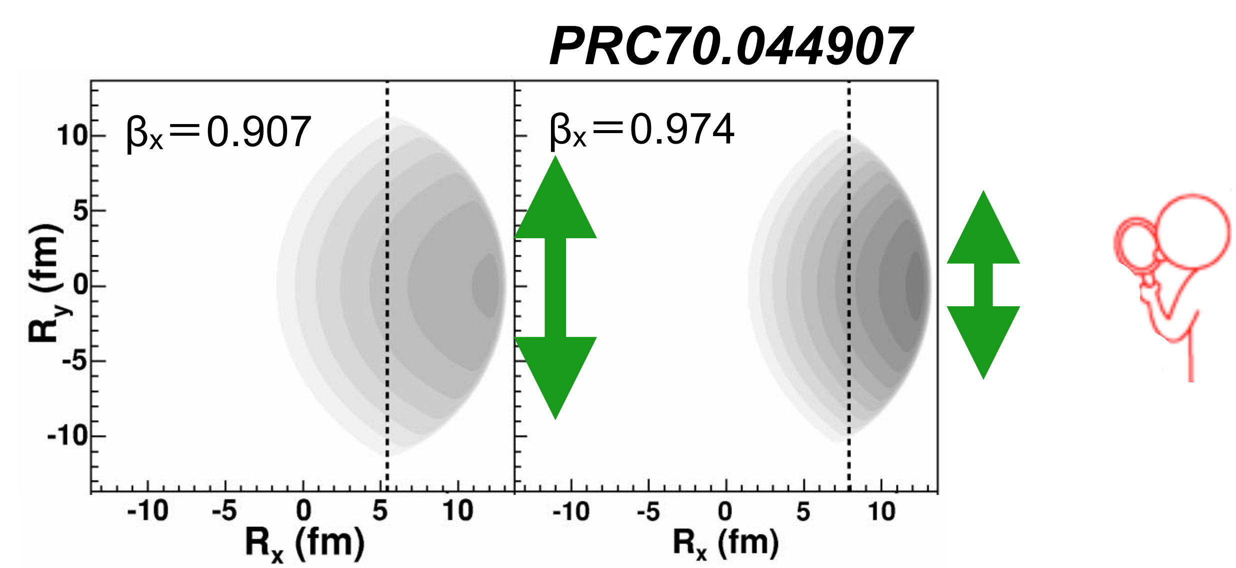
$$\vec{q}_o \parallel \vec{k}_T, \quad \vec{q}_s \perp \vec{k}_T$$

Azimuthally sensitive HBT

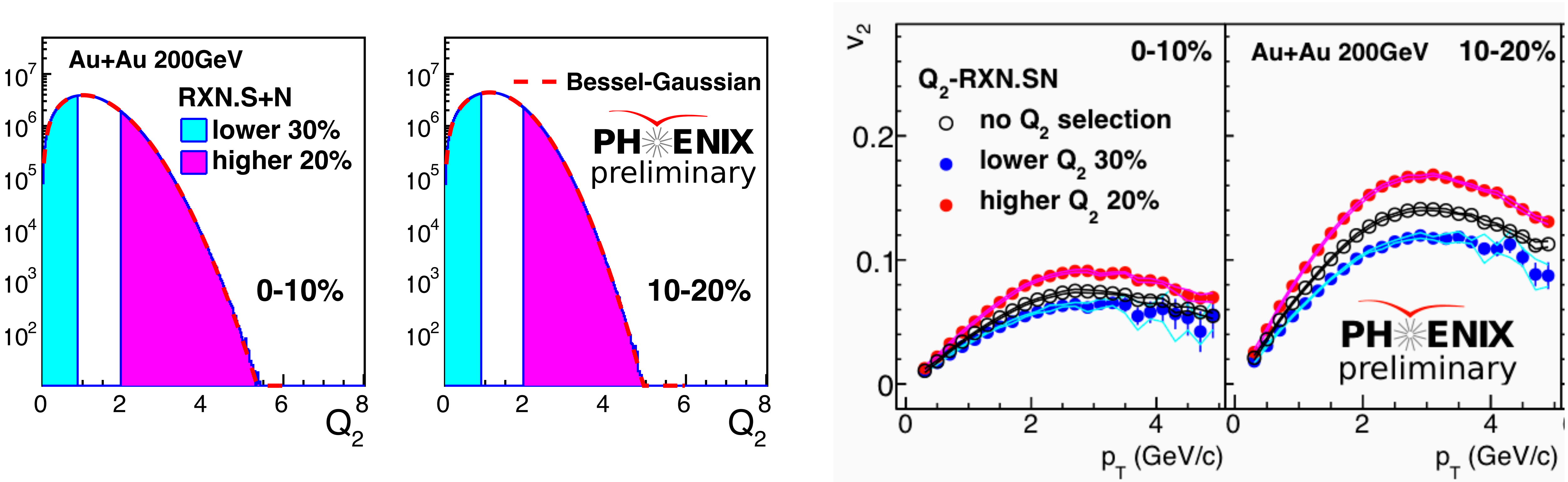


- Final source eccentricity can be probed by azimuthally differential HBT measurement

- Note: x-p correlation reduces the length of homogeneity
- But $\varepsilon_{final} \sim 2R_{s,2}^2/R_{s,0}^2$ in $k_T \rightarrow 0$
  - PRC70.044907

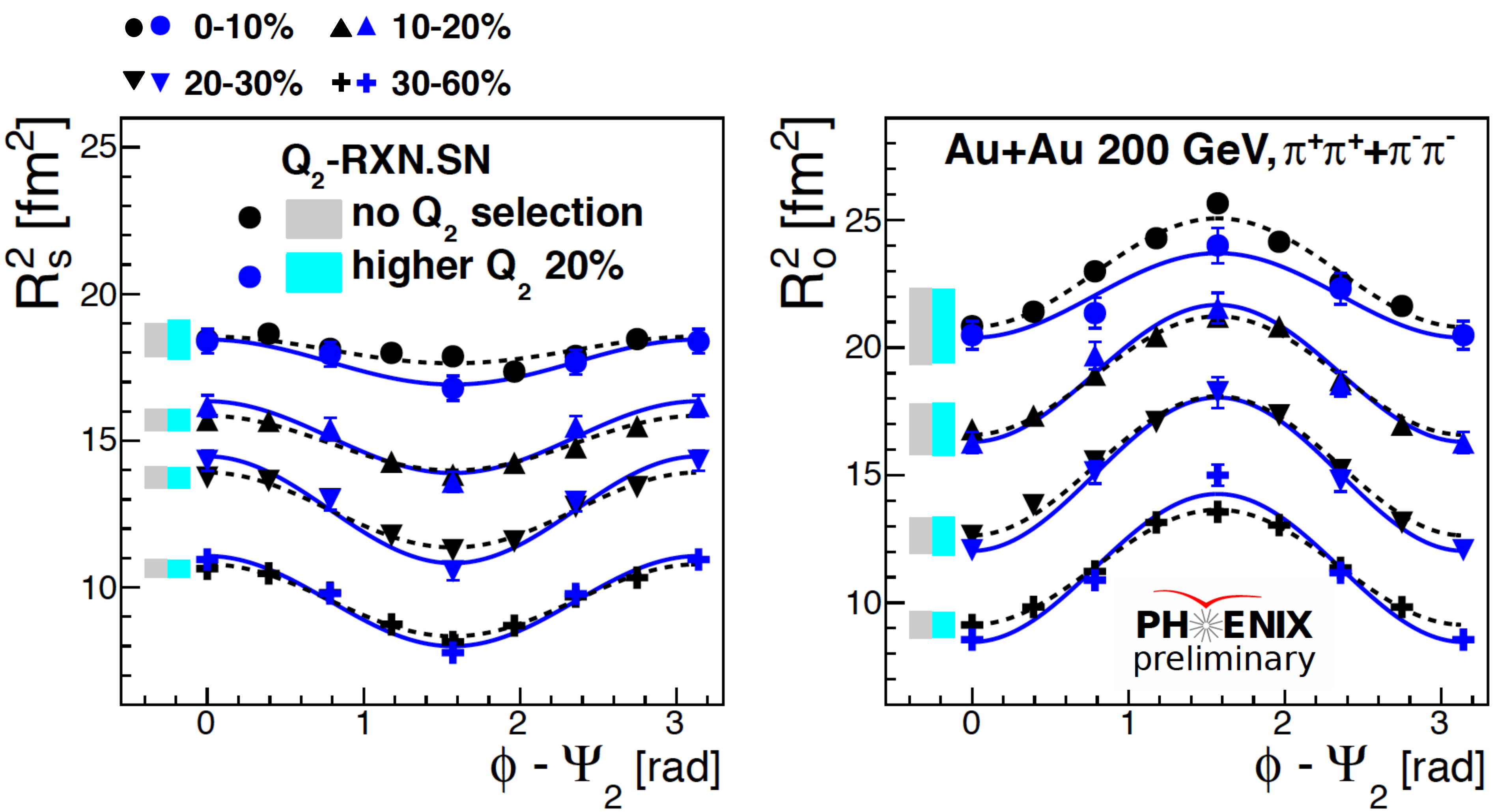


Charged hadron v_2 with ESE



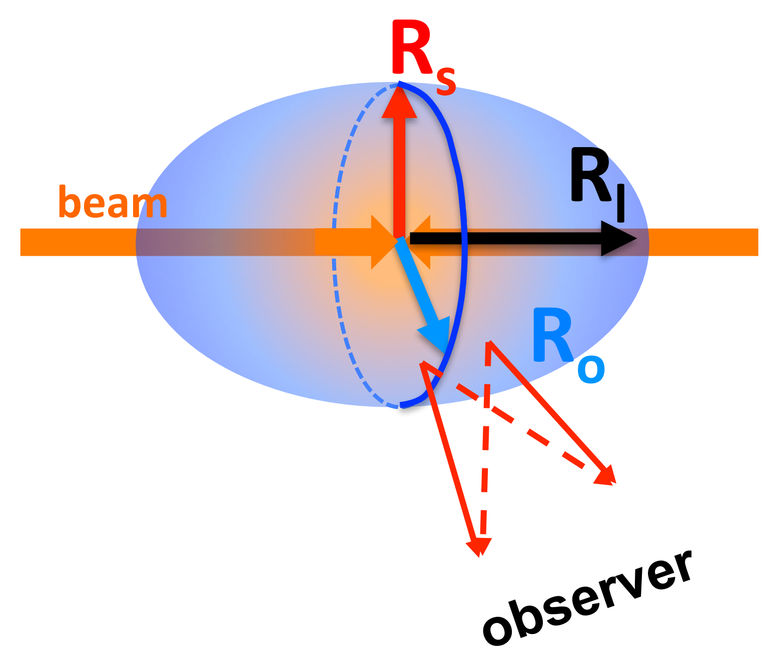
- Test of the event shape engineering in Au+Au 200GeV collisions
  - Q_2 and EP determined at $1<|\eta|<2.8$ (RxNP)
  - Charged hadron v_2 measured at mid-rapidity ($|\eta|<0.35$)
  - E.P. resolutions were estimated by 3-sub method using RxNP and BBC($3<|\eta|<3.9$) applying Q_2 selection
- Confirmed that higher(lower) Q_2 selects larger(smaller) v_2

HBT radii w.r.t Ψ_2 with ESE



$$\vec{k}_T = \frac{1}{2}(\vec{p}_{T1} + \vec{p}_{T2})$$

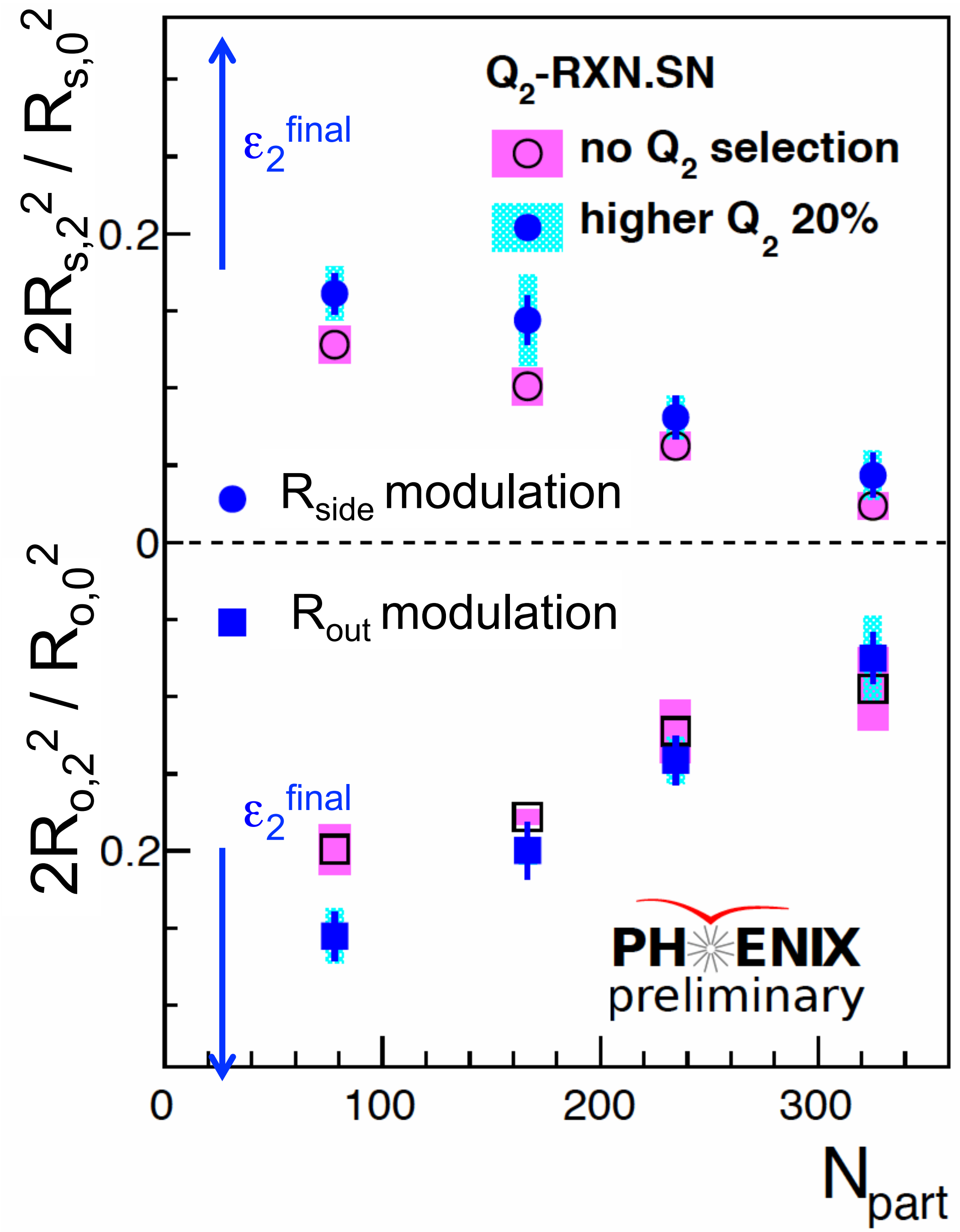
$$\vec{q}_o \parallel \vec{k}_T, \quad \vec{q}_s \perp \vec{k}_T$$



$$R_\mu^2 = R_{\mu,0}^2 + 2R_{\mu,2}^2 \cos(2\Delta\phi)$$

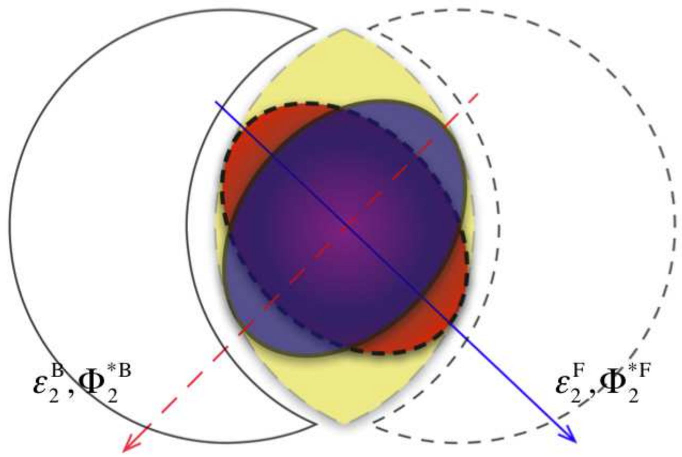
- Applying ESE to azimuthal HBT
  - charged $\pi\pi$-correlation measured at mid-rapidity ($|\eta|<0.35$)
  - Q_2 and EP determined at $1<|\eta|<2.8$
- Oscillations of R_s and R_o become larger when selecting higher Q_2 except R_o in 0-10%

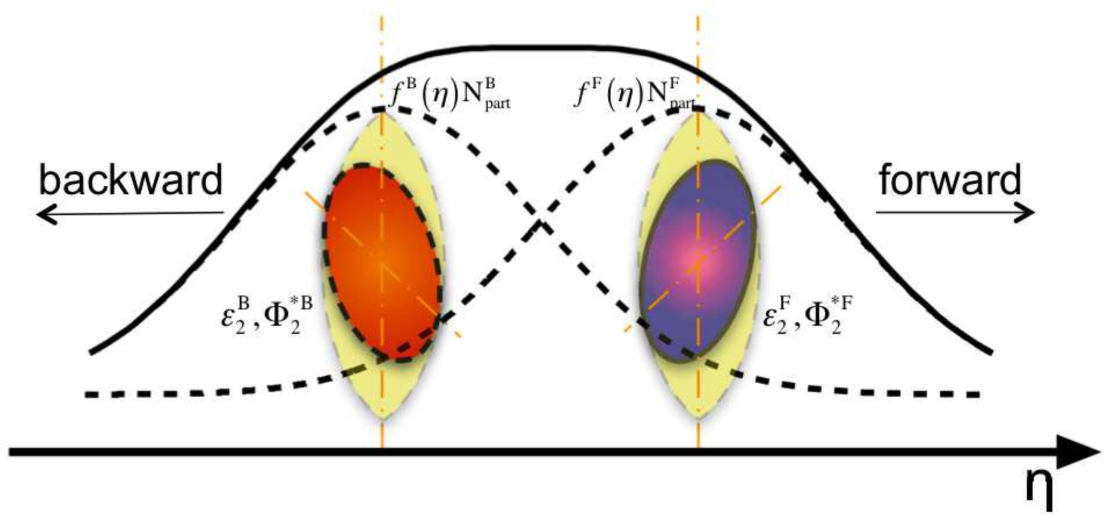
Freeze-out eccentricity vs N_{part} with ESE



- $\varepsilon_{final} \sim 2R_{s,2}^2/R_{s,0}^2$
- Higher Q_2 selection increases the measured ε_{final}
  - Selected more elliptical source at freeze-out? which might be originated from ε_{init}
  - Or just v_2 effect?

Twisted source?





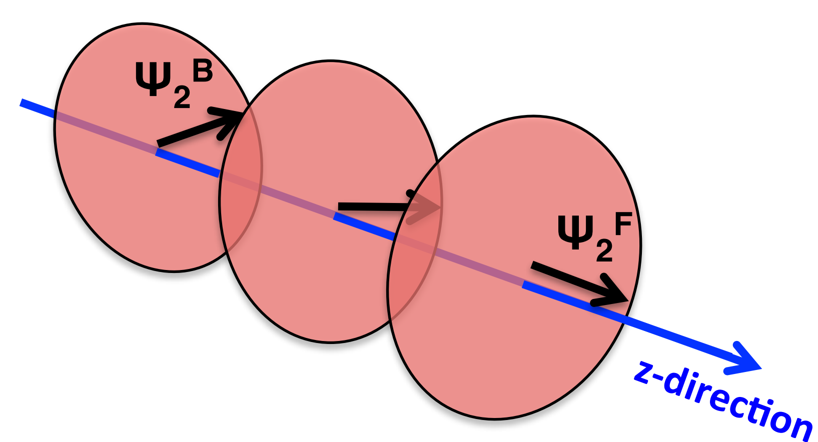
PRC90.034915

$$N_{part}^B \neq N_{part}^F$$

$$\varepsilon_n^B \neq \varepsilon_n^F$$

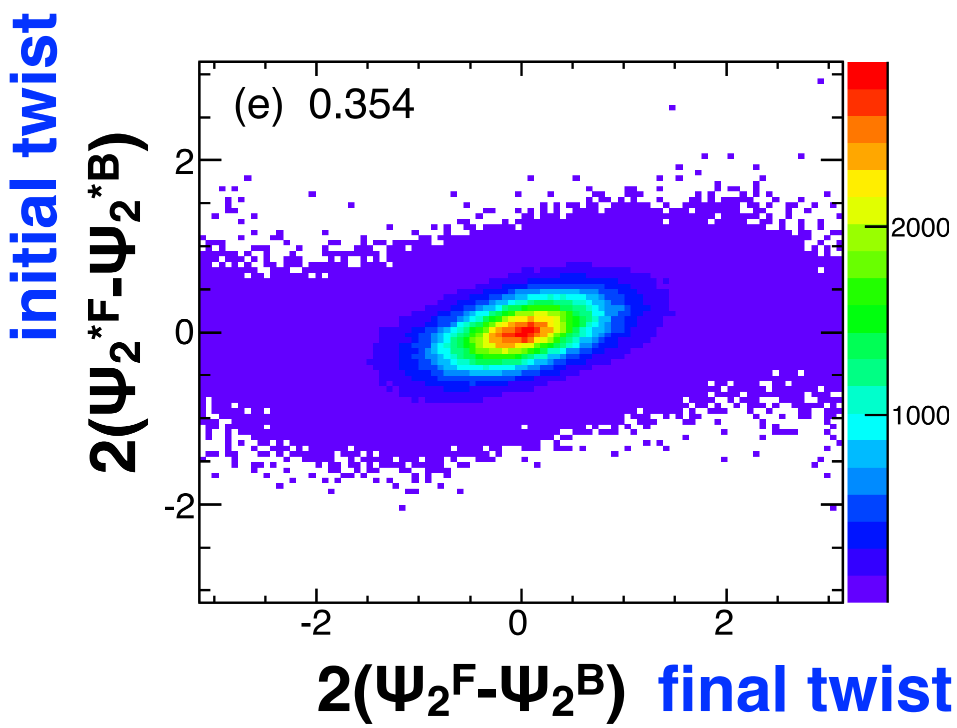
$$\Psi_{part,n}^B \neq \Psi_{part,n}^F$$

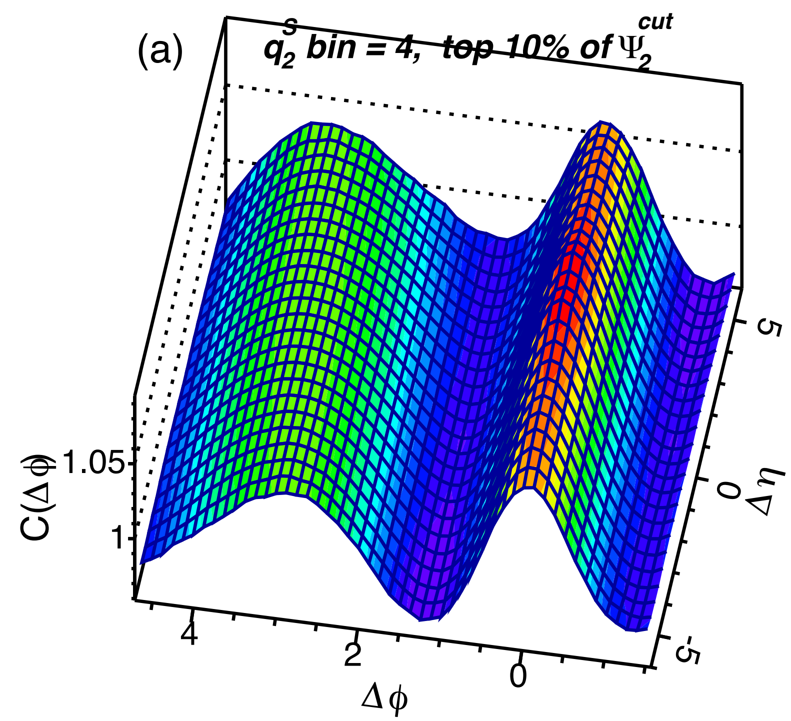
- Twisted fireball due the density fluctuation of wounded nucleons going to forward and backward directions
  - P. Bozek et al., PRC83.034911
  - J. Jia et al., PRC90.034915
- Also known as “event plane decorrelation"
  - K. Xiao et al., PRC87.011901
  - decorrelation increases with increasing η-gap
- v_n may be underestimated, which means overestimating η/s

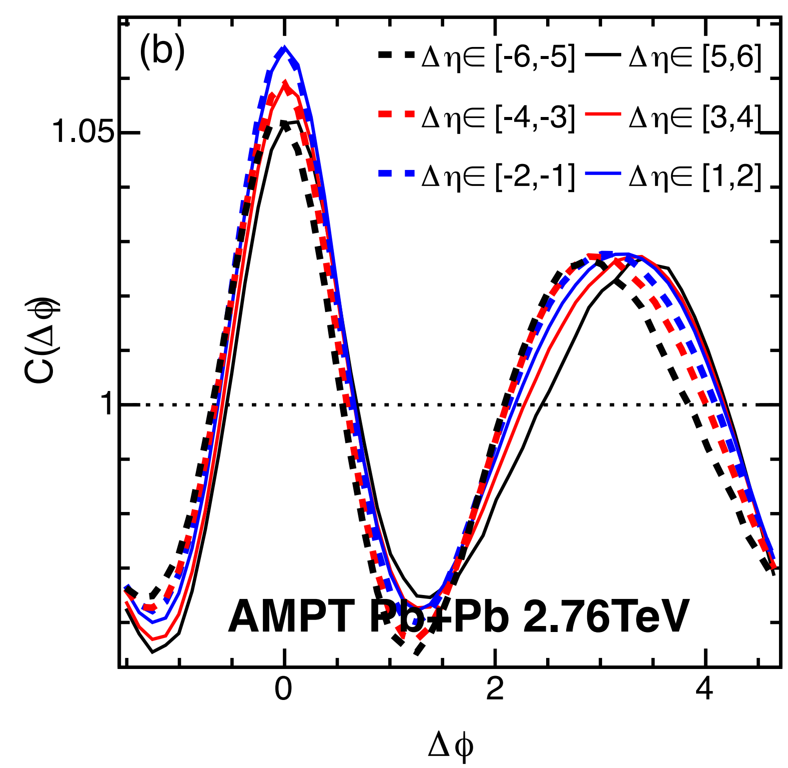


Event twist selection

J.Jia et al., PRC90.034905





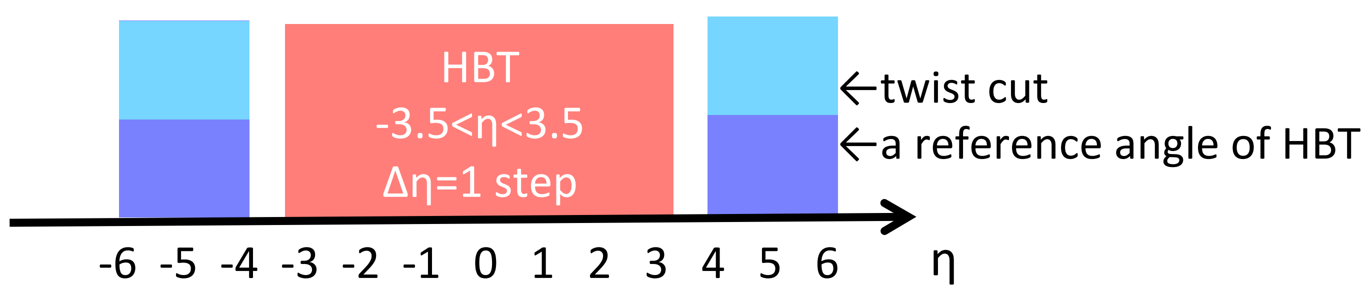


$$C(\Delta\phi, \Delta\eta) \propto 1 + 2\Sigma v_n^a v_n^b \cos(n\Delta\phi - n\Delta\phi_n^{rot})$$

- Twist effect on anisotropic flow&2PC studied with AMPT
  - Requiring finite difference b/w forward and backward EPs ($\Psi_2{}^B$-$\Psi_2{}^F$)
- Twist effect appears as a phase shift in Δϕ-Δη correlation
  - initial twist survives as a final state flow in momentum space
- Q: This twist survives in final spatial space?

HBT study in AMPT

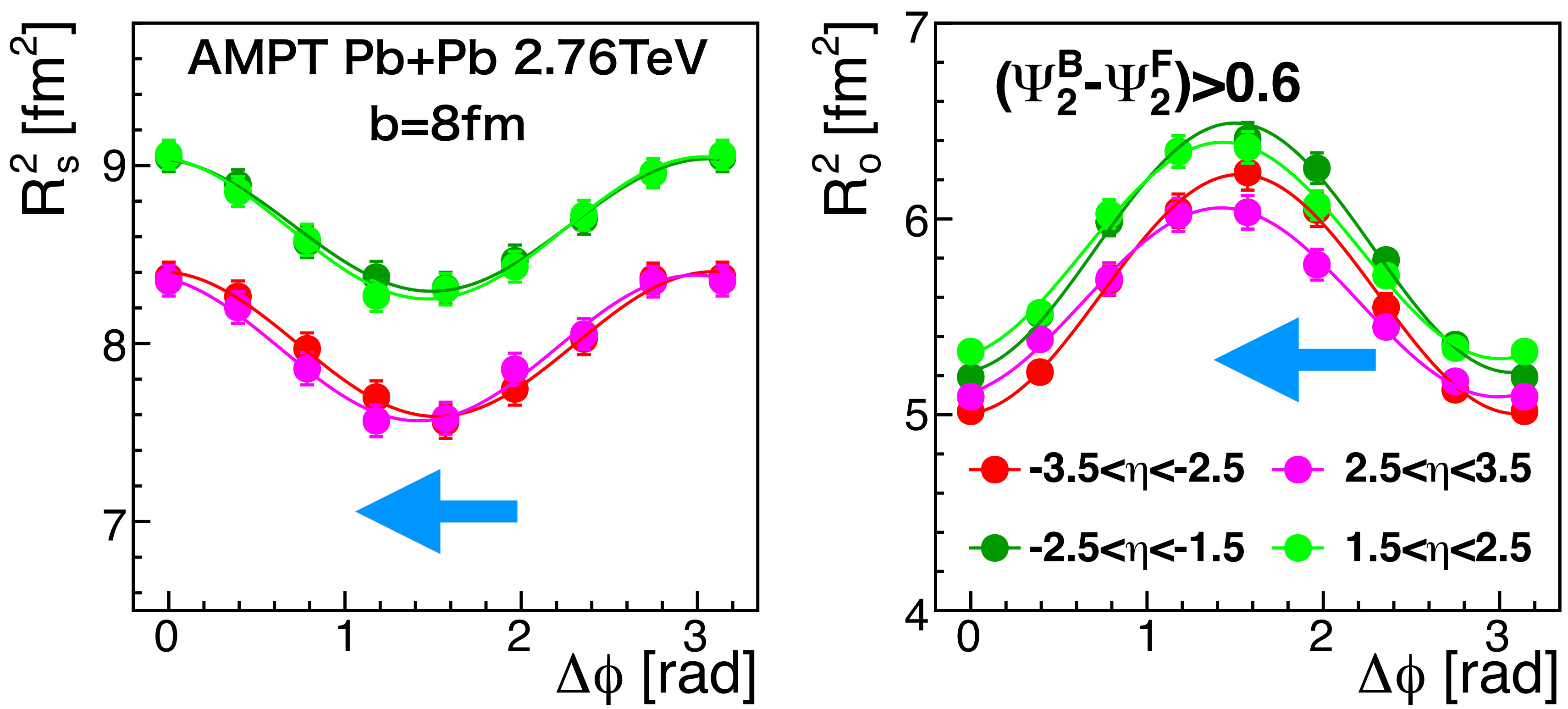
- AMPT model
  - ver.2.25 (string melting)
  - Pb+Pb 2.76 TeV collisions, b=8fm
  - initial fluctuation based on Glauber model and final state interaction via transport model
- EP determination at $4<|\eta|<6$

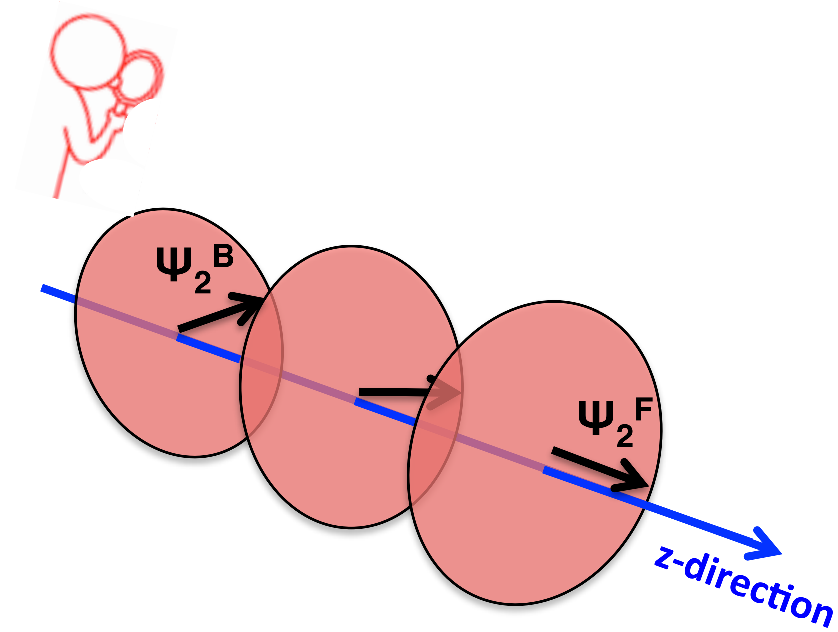


- HBT analysis
  - Add HBT correlation between two pion pairs
    - $(1+\cos(\Delta r \Delta q))$ was weighted when making q-distribution of real pairs
  - Allowing to take $\pi+\pi-$ pairs to increase statistics
    - confirmed a good agreement between $\pi^+\pi^+$ and $\pi^-\pi^-$
  - No EP resolution correction
  - Bertsch-Pratt parameterization

$$C_2 = 1 + \exp(-R_s^2 q_s^2 - R_o^2 q_o^2 - R_l^2 q_l^2 - 2R_{os}^2 q_o q_s - 2R_{ol}^2 q_o q_l - 2R_{sl}^2 q_s q_l)$$

HBT radii w.r.t backward Ψ_2

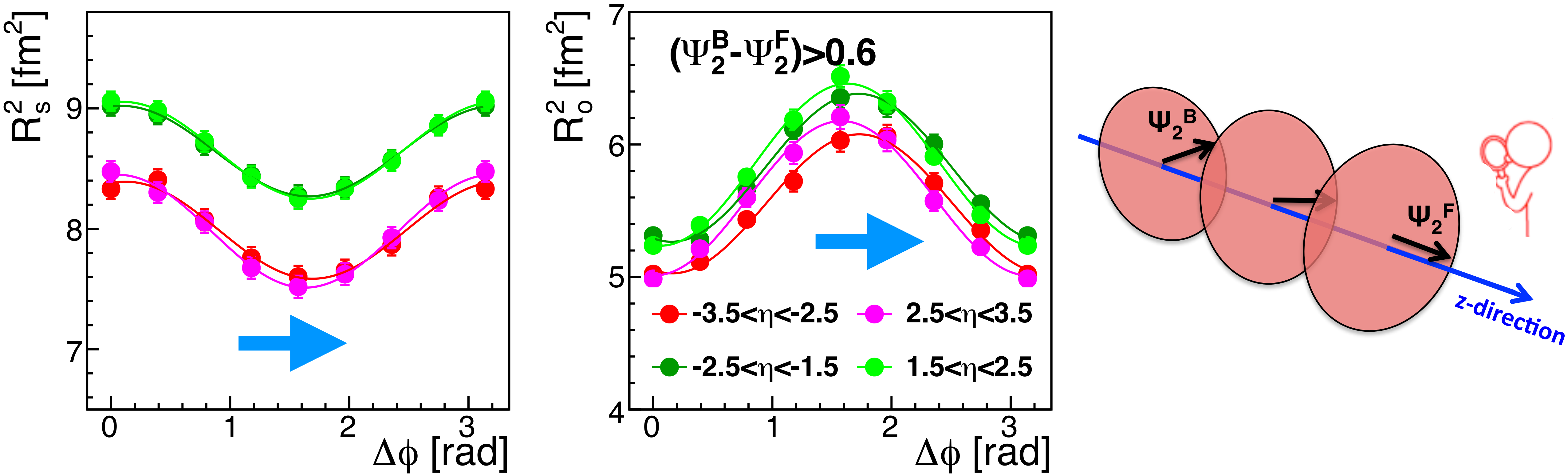




- Selected events with $(\Psi_2{}^B-\Psi_2{}^F)>0.6$
- Phase shift can be seen, and data are fitted with cosine(sine) function including a phase shift parameter α

$$R_\mu^2 = R_{\mu,0}^2 + 2R_{\mu,2}^2 \cos(2\Delta\phi + \alpha)$$

HBT radii w.r.t forward Ψ_2



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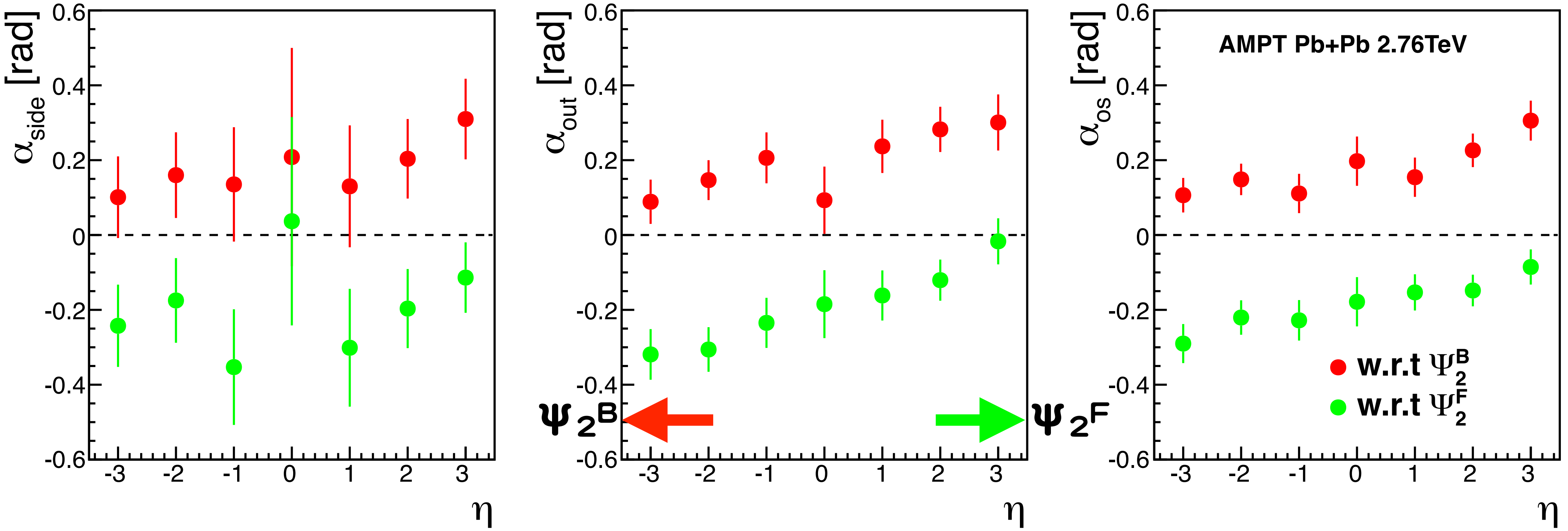
$$R_\mu^2 = R_{\mu,0}^2 + 2R_{\mu,2}^2 \cos(2\Delta\phi + \alpha)$$

η-dependence of phase shift

$$R_{\mu}^2 = R_{\mu,0}^2 + 2R_{\mu,2}^2 \cos(2\Delta\phi + \alpha)$$
$$R_{os}^2 = 2R_{os,2}^2 \sin(2\Delta\phi + \alpha)$$



- Phase shifts become larger with going far from η of a reference EP (-6<η<-4 or 4<η<6)
- Source at freeze-out might be also twisted as well as EP angles
  - It may include the effect from twisted flow
- This twist effect could be measured experimentally

Summary

- Event shape engineering at PHENIX
  - Azimuthal HBT measurement with the event shape engineering have been performed in Au+Au 200GeV collisions
  - Higher Q_2 selection enhances the measured ε_{final} as well as v_2
  - Could be more accurate relation between initial and final eccentricity
- Event twist selection with AMPT model
  - A possible twisted source have been studied via HBT measurement with AMPT Pb+Pb 2.76TeV collisions, possibly indicating the twisted source at final state
  - This effect might be measured in RHIC and the LHC, especially in ATLAS or CMS
- These technique are unique probes to the initial fluctuation and might be useful for other analyses, and Cu+Au/U+U systems

Thank you for your attention